Application of Fuzzy Based Model to Manage the Critical Risk Factors in Oil and Gas Pipeline Projects

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ABSTRACT

Although Oil and Gas Pipelines (OGPs) are safer than other modes of petroleum products transportation, enormous Risk Factors (RFs) are threatening the pipelines' safety. The uncertainty associated with data scarcity and lack of experts' judgments about the probability of occurrence and severity of the RFs are hindering the effective risk management. This paper, therefore, aims to analyse and identify the critical RFs in OGPs project using a fuzzy-based risk simulation model. The model helps to identify a suitable Risk Mitigation Method, which is useful to mitigate the critical RFs in OGP projects. A computer-based risk management tool is developed to manage the critical RFs in OGPs project.

Keywords: *Oil and Gas Pipelines; Risk Analysis; Fuzzy Inference System; Risk simulation model; Risk Mitigation Methods.*

1. Introduction

Oil and Gas Pipelines (OGPs) provide a safe and economic mode by which to transport millions of barrels of petroleum products each day. However, several Risk Factors (RFs) are threatening the safety of these pipes like corrosion, design and construction defects, natural hazards, operational errors, and many others (Daniels, 2008 and Wan and Mita, 2010). These RFs have a severe impact on people lives and the projects. Therefore, the stakeholders of these projects must have a robust risk mitigation system that can keep the RFs at the lowest level, as far as possible.

Fang and Marle, 2012 and Peng et al. 2016 stated the process of managing the RFs requires the following four steps. (I) Risk identification and registration; which means identifying the RFs that might threat OGPs based on verified recorders about OGPs, such as the records of pipelines' designs, surveillance, operational pressure, pressure test, maintenance, modification, inspections, maps of their routes, pipeline fault and accident causes (Hopkins et al. 1999). (II) Risk analysis; which means assessing the RFs regarding their probability and severity levels

(Hopkins et al. 1999). One of the problems in the existing methods of risk analysis is they are not accurate enough to analyse all the RFs, which is due to the absence of a historical database (Ge et al. 2015; Khakzad et al. 2011; Peng et al. 2016 and Yazdani-Chamzini, 2014). (III) Risk response; which means choosing the suitable Risk Mitigation Methods (RMMs) to mitigate the RFs. Therefore, it is significant to evaluate the effectiveness of the RMMs. (IV) Risk monitoring and control; which is a continuing work-cycles of the previous steps to provide up-to-date information about the existing and new RFs and RMMs.

This paper, therefore, aims to use a qualitative and statistical methodology-based and fuzzy logic theory to overcome the limitation in analysing the RFs and identify the effective RMMs associated with OGPs to enhance the safety of OGP projects.

The next section of this paper is about identifying the RFs and RMMs. The methodology of analysing the RFs and RMMs briefs in section 3. Sections 4 presents the results, and 5 discusses them. Finally, section 6 concludes the study and recommends a plan for future work.

2. Identifying the Risk Factors (RFs) and Risk Mitigation Methods (RMMs)

The inadequacy of managing several RFs that threatened OGPs disturbs oil export activities in Iraq, which is the case study in this paper. Because there was no available or accessible data that could be used to accurately identify the RFs and RMMs in OGP projects in Iraq, extensive investigations were carried out to collect data about them worldwide, and especially in the troubled countries. Based on these investigations, 30 RFs (see Table 1-A) and 12 RMMs (see Table 2-A) were identified in this paper. However, there is still a lack of data about the probability and severity of RFs and the effectiveness of RMMs. Therefore, the RFs and RMMs will be analysed based on a questionnaire survey and a computer-based model (as will be exhaling in section 3).

3. Research Methodology

This paper has followed 2 steps to analyse the RFs and RMMs in OGPs. Step 1 was about designing a questionnaire survey based on the finding of section 2. The purpose of this questionnaire is to collect the perceptions of the stakeholders about the “probability and severity” levels of the RFs and the “effectiveness” levels of RMMs (see sections 3.1 and 3.2). Step 2 was about using the findings of step 1 as inputs for a fuzzy-based simulation model that was developed using the Fuzzy Inference System (FIS) toolbox of MATLAB to analyse the

RFs (see section 0). The findings of these two steps will be used to make some recommendations to mitigate the RFs.

3.1. Questionnaire Design

In the questionnaire, the respondents were asked to evaluate the probability of the RFs on a scale of [almost certain, likely, possible, unlikely, and rare], and the severity of them has evaluated a scale of [catastrophic, major, moderate, minor, and negligible]. The effectiveness of the RMMs has evaluated on a scale of [extremely effective, very effective, moderately effective, slightly effective, and insignificant]. The participants were assured that their participations identify and answer would be analysed confidentially.

3.2. Traditional Risk Ranking

The mean of each scale was calculated to determine the numerical values of Risk Probability (RP), Risk Severity (RS) (see Table 1-B) and the effectiveness of RMMs (see Table 2-B). The Risk Index (RI) values were calculated for each RF using equation 1 (Jamshidi et al. 2013; Yadav et al. 2003 and Yazdani-Chamzini, 2014).

$$RI = (RP \times RS)/5 \quad \dots (1)$$

Initially, as shown in Table 1-C, the RFs were ranked based on their values of RI. Nevertheless, using the RI method to rank the RFs does not adequately reflect the criticality of the risks. Perhaps an RF has a high severity value, which means this RF needs urgent mitigation work before it threats the projects. However, the same RF will not get a high rank if its' probability is low, and vice versa. Moreover, as Dai and Li (2010) and Yazdani-Chamzini and Zavadskas (2011) concluded, uncertainty could arise during risk analysis due to data scarcity or incomplete information about the RFs and experts' judgments about them. In such a situation, the fuzzy logic theory is a useful tool that can be employed to handle risk analysis when there are no precise values and sharp boundaries (Zadeh, 1965). Because fuzzy logic uses expressions and linguistic labels instead of rigid mathematical rules and equations to model the behaviour of a system or sub-system (Yazdani-Chamzini, 2014). Therefore, a computer-based risk simulation model has been developed in section 0 to analyse the RFs using fuzzy logic theory.

3.3. Risk Simulation Model

As shown in Figure 1, the process of the FIS has the following three stages. (I) Fuzzification, which is about providing crisp inputs ‘e.g. RP and RS’ for the FIS. (II) The knowledgebase, which is about defining the membership functions for the inputs and outputs of the model (see Figure 3) and defining the ‘If-Then rules’ to control the FIS. (III) Defuzzification, which is about obtaining the final outputs ‘RI’ (see Figure 2).

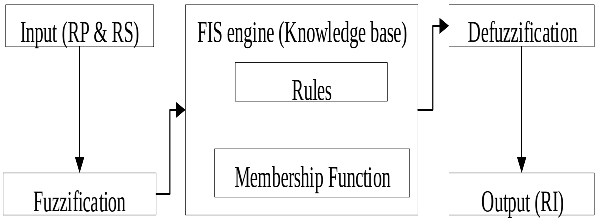

Figure 1: The prototype computer-based risk simulation model using FIS (Jamshidi et al. 2013; Li et al. 2010 and Sa’idi et al. 2014).

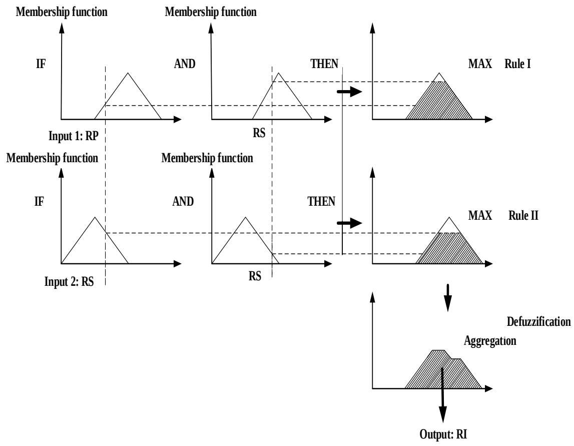

Figure 2: The Min-Max membership function of the FIS (Zadeh 1965).

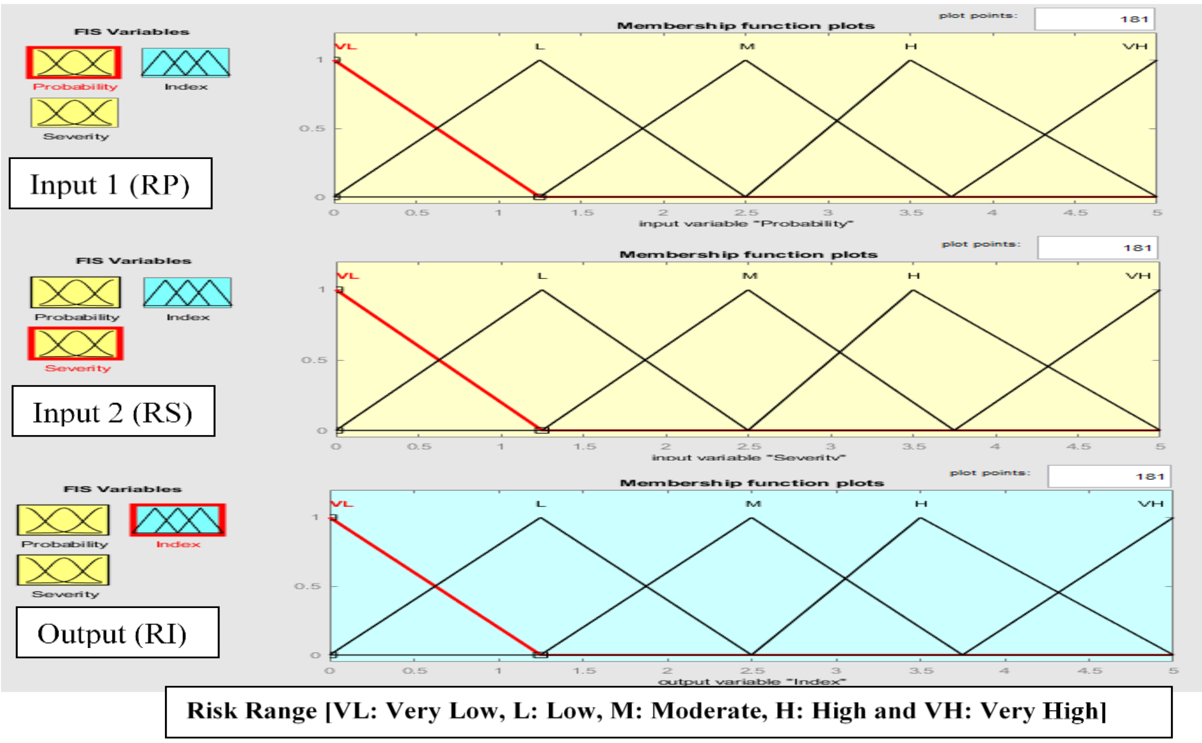

Figure 3: Triangular fuzzy membership functions.

4. Results

A total of 198 respondents have participated in the survey in which, 14 of them were consultants, planners or designers, 71 were members of a construction team, 41 were operators and 39 of them were owners or clients. The Cronbach's alpha correlation coefficient (α) was calculated to measure the reliability level of the survey (Cronbach, 1951 and Webb et al. 2006). The survey was found reliable because the α of the survey was 0.910 when 0.7 indicates a minimum level of reliability (Pallant, 2001). Table 1 shows the results of identifying the RFs; as well as, the results of analysing them.

Table 1: The results of identifying, analysing and ranking the RFs.

A- The findings from section 2. (Kraidi et al., 2017a, 2017b)	B- Survey's results		C- RI results		D- FIS' results		
RFs	RP	RS	RI	Rank	FIS	R	Range
Terrorism & sabotage	3.995	4.490	3.59	1	3.99	1	H
Corruption	3.980	4.323	3.44	2	3.87	2	H
Low public legal & moral awareness	3.712	4.106	3.02	4	3.80	3	H
Insecure areas	3.717	4.192	3.05	3	3.76	4	H
Thieves	3.692	4.081	3.01	5	3.75	5	H
Corrosion & lack of protection against it	3.687	3.990	2.94	6	3.72	6	H
Lack of proper training	3.646	3.859	2.80	11	3.71	7	H
Improper safety regulations	3.687	3.960	2.91	7	3.70	8	H
Exposed pipelines	3.667	3.949	2.87	8	3.70	9	H
Improper inspection & maintenance	3.657	3.899	2.83	10	3.69	10	H
Conflicts over land ownership	3.495	3.646	2.57	19	3.68	11	H
Shortage of the IT services & modern equipment	3.667	3.924	2.86	9	3.68	12	H
Weak ability to identify & monitor the threats	3.631	3.848	2.75	12	3.67	13	H
Design, construction & material defects	3.333	3.611	2.48	21	3.64	14	H
Lack of historical records about accidents and risk registration	3.566	3.662	2.64	17	3.60	15	H
The pipeline is easy to access	3.631	3.773	2.70	13	3.57	16	H
Limited warning signs	3.626	3.732	2.68	14	3.56	17	H
Little research on this topic	3.621	3.697	2.66	15	3.55	18	H
Lawlessness	3.606	3.682	2.65	16	3.54	19	H
Stakeholders are not paying proper attention	3.530	3.652	2.59	18	3.51	20	H
Public's poverty & education level	3.449	3.611	2.52	20	3.49	21	H
Inadequate risk management methods	3.227	3.505	2.24	23	3.48	22	H
Leakage of sensitive information	2.980	3.399	2.09	25	3.38	23	H
Threats to staff (kidnap or murder)	3.323	3.571	2.35	22	3.35	24	H
Operational errors e.g. human error and equipment failure	3.101	3.409	2.19	24	3.30	25	H
Geological risks like soil movement and landslides	2.747	3.182	1.75	26	3.17	26	H
Natural disasters & weather conditions	2.652	3.066	1.63	27	3.10	27	H
Hacker attacks on the operating or control system	3.066	3.066	1.33	29	3.03	28	H
Vehicle accidents	2.465	2.970	1.34	28	2.80	29	M
Animal accidents	1.894	2.020	0.77	30	1.95	30	L

For example: $RI\ for\ Terrorism\ \&\ sabotage = (3.995\ \times 4.490)/5 =\ 3.587.$

Table 2 shows the results of identifying the RMMs; as well as, the results of evaluating them.

Table 2: The results of identifying and evaluating RMMs.

A- The findings from section 2 (Hopkins et al. 1999; Rowland, 2010).	B- Survey's results
Risk Mitigation Methods	Effectiveness
Anti-corrosion such as isolation & cathodic protection	4.23
Move to an underground pipeline	4.07
Advanced technological & professional remote monitoring	4.0
Proper inspection, tests & maintenance	3.83
Proper training	3.79
Avoid insecure areas	3.78
Anti-terrorism design	3.78
Avoid registered risks & threats	3.77
Protective barriers & perimeter fencing	3.69
Government/public cooperation	3.57
Warning signs & marker tape above the pipeline	3.55
Foot & vehicle patrols	3.53

Figure 4 shows an automatic tool using Excel 2016 to choose the suitable RMMS for the RFs. The RMMs were ranked based on the survey results. An example about how to use this tool is shown in this figure; first, we should select the RF from the RFs list then the RMM(s) from the RMMs list. Moreover, Table 3 shows the suggested RMMs to mitigate the RFs in OGP projects in Iraq.

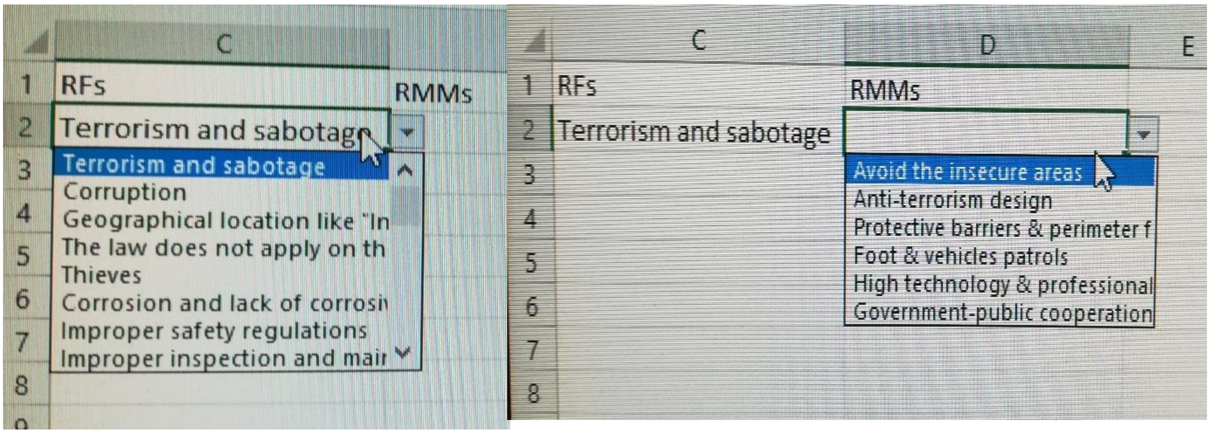

Figure 4 the Excel sheet

Table 3: The suggested RMMs to mitigate the RFs

RFs	RMMs
Terrorism & sabotage Thieves Geographical location “insecure areas" Public's Low legal & moral awareness	Avoid the insecure areas Anti-terrorism design Protective barriers & perimeter fencing Foot & vehicles patrols High technology & professional remote monitoring Government-public cooperation
Threats to staff The pipeline is easy to access	Foot & vehicles patrols Use underground pipeline High technology & professional remote monitoring Protective barriers & perimeter fencing Foot and vehicles patrols
Geological risks such as groundwater & landslides	Anti-corrosion such as isolation and cathodic protection
Vehicles accidents	Use underground pipeline Protective barriers and perimeter fencing Warning signs & marker tape above the pipeline
Animals accidents on the pipeline	Use underground pipeline Protective barriers & perimeter fencing
Corrosion and lack of protection against it	Anti-corrosion such as isolation & cathodic protection
Weak ability to identify & monitor the threats Shortage of the IT services & modern equipment	High technology & professional remote monitoring Avoid insecure areas High technology & professional remote monitoring
Design, construction & material defects	Anti-corrosion such as isolation & cathodic protection Anti-terrorism design Avoid the registered risks & threats
Operational errors	High technology & professional remote monitoring Proper inspection, tests & maintenance Proper training
Lack of proper training	Proper training

5. Discussion

Collecting the required information about the RFs and RMMs from various trusted sources like the previous literature and the completed surveys will provide real information to guide future actions relating to OGP risk management. Moreover, to overcome the uncertainty about analysing the RFs, they have been assessed by using a computer-based risk simulation model, which was conducted using the fuzzy logic theory (see Figures 1 and 2 above).

The RFs were ranked twice using two different methods. Firstly, the RFs were based on their values of RI. Secondly, the RFs were ranked based on the results of FIS. Comparing these two ranks, there was no change for only 8 out of 30 RFs, which are the 1st, 2nd, 5th, 6th, 10th, 26th, 27th and 30th RFs. FIS can overcome the uncertainty in the analysis of the RFS because it classifies them by sets of ranges [very low, low, moderate, high, and very high] (see Figure 3).

Such classification helps to rank the RFs by their ranges of risk rather than uncertain values of RI. Furthermore, FIS provides a powerful 3D risk matrix, which helps to view the RFs by their zones of influence on pipeline projects, as shown in Figure 5.

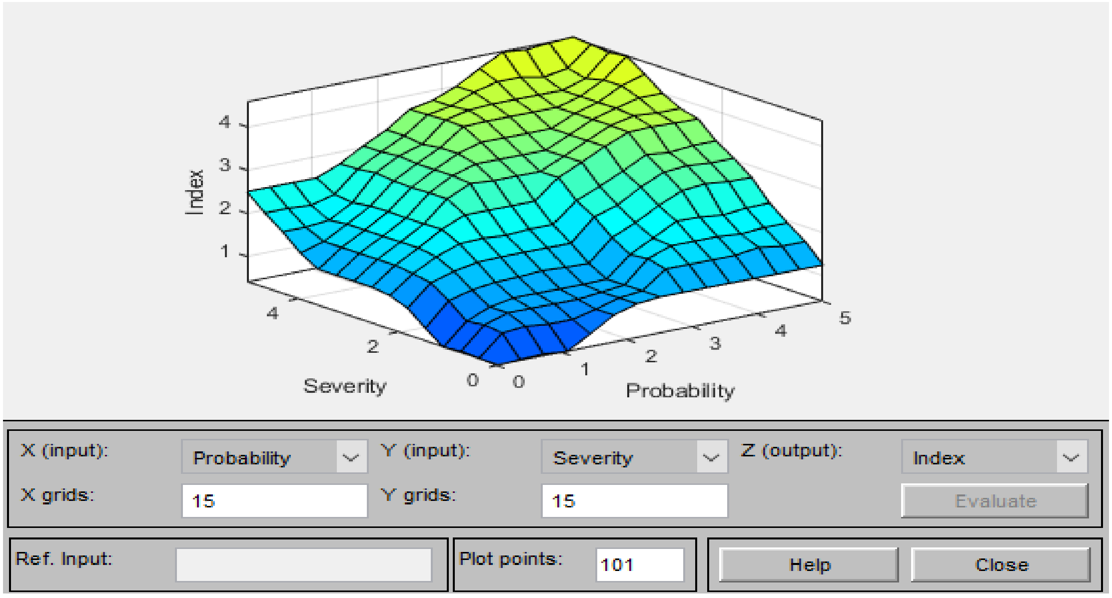

Figure 5: 3D risk in FIS

Based on the survey results, anti-corrosion measures such as isolation and cathodic protection were rated as effective RMMs. That said, foot and vehicle patrols are not effective RMMs.

In this paper, we have developed a tool that has a list evaluated and ranked RMMs that are suggested to mitigate RFs in OGPs in Iraq. The inputs of this tool are a list of RFs and a list of evaluated and ranked RMMs, and the outputs are the suitable RMMs. The stakeholders could use these findings for risk management for OGP projects. In the future, an up-to-date and more automated tool will be provided for the purpose of risk management in OGPs projects.

6. Conclusion and Future Work

Risk management cannot protect pipelines from all RFs. Meanwhile, it should recognise the best way to mitigate the RFs. The results of the questionnaire survey were used to provide inputs for a computer based-model that was developed to analyse the RFs by using the FIS toolbox of MATLAB. Using fuzzy logic in the process of the risk assessment remedies the problems of the traditional approaches to risk management.

Assessing the RFs using FIS shows the range of the risk is from low to high. The risk simulation model shows that terrorism, official corruption, insecure areas, and lawlessness are the most critical RFs in OGP projects in Iraq. Therefore, different risk mitigation methods should be suggested to mitigate these RFs. At the same time, the results revealed that the anti-corrosion efforts are the most effective RMMs.

In the future work, we will estimate the consequence the hazardous events we will use a neural network analysis tool to draw some pipe failure scenarios. As well as, one of the decision support methods that can analyse the inputs (e.g. RFs, RP, RS, RMMs, the effectiveness of RMMs and the cost) will be developed to help the stakeholders during the decision-making process.

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